Chicago PET Development and Recent Progress in Digital TOFPET

1. Heejong Kim, Chien-Min Kao, Qingguo Xie, Yun Dong, Ming-Chi Shih, Antonio Machado, and Chin-Tu Chen
2. Octavia Biris, Jialin Lin, Fukun Tang, Lin Zhou, and Henry Frisch
3. Robert Wagner, Karen Byrum, and Gary Drake
4. Woon-Seng Choong and William Moses

- 1. Department of Radiology & Committee on Medical Physics, University of Chicago, IL
- 2. Enrico Fermi Institute & Department of Physics, University of Chicago, IL
- 3. High Energy Physics Division, Argonne National Laboratory, Argonne, IL
- 4. Lawrence Berkeley National Laboratory, Berkeley, CA
Quantitative Imaging
Multi-Modality Integration
High-Performance
Low-Cost
Broad-Access
PET Imaging Chain and UC PET R&D

Clinical Outcomes & Biological Discoveries
[Cancer, Cardiac, Brain, Drug, etc.]

Performance Evaluation
[Task-Based Assessment]

Quantitative Image Analysis
[MM QIA & List-Mode Dynamic 4D/5D QIA]

Cyclotron/Radiotracer
[Multi-Modality Probes]

Subject
(Human/Animal)

Integration with Medicine & Biology

Detector & System
[Panel-PET & SiPM]

Electronics
[Digital PET]

Image Reconstruction
[MM-IR & ROI-IR]
Imaging of Life and Life Processes

Live Brain

MR
PET

Dead Brain

MR
PET
Task-Based Image Quality Assessment

Tasks – Detection and Estimation

Whole Body PET Study using $^{18}$FDG ($^{18}$F-fluorodeoxyglucose)--60 minutes
2008 IEEE NSS/MIC/RTSD
MIC Short Course
"Image Quality in Adaptive and Multimodality Imaging"
20 October 2008
Dresden, Germany

Organizer: Harrison Barrett,
Matthew A. Kupinski,
Lars R. Furenlid
PET Imaging Chain and UC PET R&D

Clinical Outcomes & Biological Discoveries
[Cancer, Cardiac, Brain, Drug, etc.]

Performance Evaluation
[Task-Based Assessment]

Quantitative Image Analysis
[MM QIA & List-Mode Dynamic 4D/5D QIA]

Cyclotron/ Radiotracer
[Multi-Modality Probes]

Subject
(Human/Animal)

Integration with Medicine & Biology

Detector & System
[Panel-PET & SiPM]

Electronics
[Digital PET]

Image Reconstruction
[MM-IR & ROI-IR]
Key Characteristics of Biomarker Generator

- Lower cost & much smaller to be located at scanner
- To be an approved FDA medical device
- Produce dose of F-18 or C-11 biomarker in 20 minutes
- Base chemistry system for drug discovery
- Handling of micro to millicuries, not curies

Microchemistry & Microfluidics

Courtesy of Nanotek & ABT
Multi-Modality Targeting Molecular Imaging & Therapeutic Probes (Phage and Micelle Nanosystem)

T7 bacterium virus (phage)

Size: ~50 nm in diameter

Components:
Capsid shell, head-tail connector, tail, tail fibers.

Fabrication of hybrid Tc-99m phage particle

Ultrasound, MRI, SPECT, PET, X-Ray/CT, Fluorescence & Therapeutics
Image Co-Registration & Integration

Fusion of PET, SPECT, MRI, CT, EPRI, Histology

Halpern, Pelizzari Karczmar Weichselbaum
Windowed image reconstruction for time-of-flight positron emission tomography

Chien-Min Kao

600 ps

2 ns
Silicon PM Characterization

MPPC: 1x1mm$^2$
25-μm, 50-μm, or 100-μm

Source: F-18

LYSO: 1x1x10mm$^3$, 2x2x10mm$^3$
F-18/LYSO Sample Pulses

![Voltage vs. Time Graphs for PMT, 25-μm MPPC, 50-μm MPPC, 100-μm MPPC]
A Table-Top Prototype

The prototype consists of two HRRT (High Resolution Research Tomograph) detector heads. The spacing between detectors shown is ~6 cm, which is adequate for imaging rodents.

A single double-layered, 8 x 8 LSO crystal block affixes onto 4 photomultiplier tubes in the quadrant-sharing configuration.
Central Sensitivity
(GATE Simulation, 20% ER, 3ns TR)
Noise-Equivalent Count Rate
Comparison with reported NECR peaks

Mouse

Rat

Reported NECR peaks
FDG Resolution phantom
real data

Modeling the responses by MC simulation

Ideal line integral
Sample Image
real FDG-Rat data

Ideal line integral

Modeling response
Initial FDG-Rat Images
PET Imaging Chain and UC PET R&D

Clinical Outcomes & Biological Discoveries
[Cancer, Cardiac, Brain, Drug, etc.]

Performance Evaluation
[Task-Based Assessment]

Cyclotron/Radiotracer
[Multi-Modality Probes]

Subject
(Human/Animal)

Integration with Medicine & Biology

Electronics
[Digital PET]

Detector & System
[Panel-PET & SiPM]

Image Reconstruction
[MM-IR & ROI-IR]

Quantitative Image Analysis
[MM QIA & List-Mode Dynamic 4D/5D QIA]
Digital PET Data Acquisition
A Multi-Threshold Approach

PMT IN -> discriminators

\[ V_1 \rightarrow \text{TDC} \]
\[ V_2 \rightarrow \text{TDC} \]
\[ V_3 \rightarrow \text{TDC} \]
\[ V_4 \rightarrow \text{TDC} \]
Multi-Threshold Approach

- Sampling pulse at pre-defined voltage levels.
- Output: only digitized timings.
- Pulse reconstruction using digitized timings.
- Remove analog blocks.
  (Pre-Amp, ADC, CFD)
- Digital Signal Processing (DSP) technology can be utilized.
  (event time, energy)

PMT waveform by 20GS/s oscilloscope superimposed with timing readouts by the multi-threshold board + HPTDC

$\chi^2 / \text{ndf} = 280.9 / 2$
$p_0 = -2888 \pm 15.96$
$p_1 = 184.4 \pm 0.9637$
Multi-Threshold Board + HPTDC

Multi-threshold discriminator board
• 2 boards with 4 channels in each.
• 0-700mV of adjustable threshold level.
• Used ADCMP582 comparators.
• Timings at leading and falling edges.

High Performance TDC (HPTDC)
8/32 channels.
25 ps/bit.
developed at CERN.

Multi-threshold board (left) connected to HPTDC module (right).
Experimental Setup

- Two Hamamatsu R9800 photomultiplier tubes (HV = -1,300V)
- Coupled with LSO crystals (6.25x6.25x25mm³)
- Separated 5cm apart
- Na-22 used for positron source located at the center
- Multi-threshold discriminator board setup:
  - Inputs from 2 PMT signals
  - Thresholds: 50, 100, 200, 300mV
- Timing Readout:
  - TDS6154 oscilloscope20GS/s.
    - HPTDC.
  - (8chs, 25 ps/bit, developed at CERN)

A Block diagram of the setup.
Time Resolution of Discriminator

- Sent pulse generator signals to two channels.
- Measured time difference with the TDS6154 oscilloscope.
- Time resolution of single channel: \(~13.3\text{ps}(\text{FWHM})\)

Time offset between two channels of the Multi-threshold discriminator.
Pulse Reconstruction (HPTDC)

• Select the gamma coincidence events. events with 2, 3 and 4 hits from each board.

• Reconstructed pulse shape.

• Linear fit on the leading edge. (event time).

• Exponential fit on the falling edge. (energy, decay constant)

Energy distribution of 511keV gamma.
Pulse Reconstruction - 2

The decay time constant.
Coincidence Timing Resolution

- Select the coincidence events.
- Least square fit to the leading edge timings.
- Use two leading edges with 100, 200mV thresholds.
- Extrapolated at 0mV.
- The time difference, t1-t2. (FWHM)
  - Oscilloscope: 330ps
  - HPTDC: 350ps

Time difference of 511keV gamma coincidence events
PET Imaging Chain and UC PET R&D

Clinical Outcomes & Biological Discoveries
[Cancer, Cardiac, Brain, Drug, etc.]

Performance Evaluation
[Task-Based Assessment]

Quantitative Image Analysis
[MM QIA & List-Mode Dynamic 4D/5D QIA]

Cyclotron/Radiotracer
[Multi-Modality Probes]

Subject
(Human/Animal)

Integration with Medicine & Biology

Detector & System
[Panel-PET & SiPM]

Electronics
[Digital PET]

Image Reconstruction
[MM-IR & ROI-IR]
Motor Activity Study (Stroke)
Motor Activity Studies